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1930 Electricity

SOME RESEARCH FEATURES OF THE APPLICATION OF ELECTRICITY TO AGRICULTURE.*

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INTRODUCTION

The purpose of this paper is to bring to light and analyze in a preliminary manner some of the apparently more important research features involved in a proposed development, having for its ultimate objective the exclusive use of electricity in all agricultural processes requiring a tangible source of energy.

Data are available from various sources to show that the cost of actual production of electrical energy is in many cases a relatively small item as compared with the costs of transmission, distribution, and transformation. It is easy to understand therefore that with the long distance transmission required and the relatively small number of consumers per mile of transmission, American agriculture can not hope to generally secure central station electrical service at urban rates as long as there is no greater rural consumption of electrical energy than that incident to lighting and the miscellaneous small belt and shaft jobs in the house and around the farmyard.

Obviously American agriculture can not successfully utilize electrical energy unless the cost thereof and the returns from the processes employing it are such as to make the practice a profitable one. Just as obviously the central stations can not be expected to invest money in equipment for meeting a rural load unless that load is large and constant enough to pay a reasonable return on the investment.

It therefore logically follows that the only way to lower the cost of central station energy to a rate at which its general use in agriculture is profitable, is to increase its profitable agricultural use to such an extent that the resulting load corresponds to a reasonable rate of profit for both the central station and the individual farmers.

With this in view and at the request of the Committee on the Relation of Electricity to Agriculture, the Office of Experiment Stations of the U. S. Department of Agriculture undertook an impartial study of the research features of the subject with a view to formulating an investigational and research program to serve as a guide to State institutions and others in the planning and conduct of developmental research on profitable uses of electricity in agricultural processes. This paper constitutes a preliminary progress report of this study to date.

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SCOPE OF THE STUDY

It would seem best for present purposes to assume that electrical energy of the proper voltage is avaiable to farmers. This eliminates the purely electrical engineering phases of production, transmission, and transformation for the time being, the problems of which are obvious logical responsibilities of the electrical people themselves. Of course the nature of such transmission and transformation should be governed largely by the general requirements of farming, and the definite formulation of such requirements for the information and guidance of the central stations is one of the important ultimate considerations. However, before these broad general requirements can be formulated with any degree of finality for different types of agriculture, it would seem necessary to first confine consideration of the problem to its agricultural and agricultural engineering phases to determine the nature of the requirements of the individual processes involved.

Consultation with agricultural engineers throughout the United States and with specialists in other branches of agriculture revealed the strong probability that the problem of the application of electricity to agriculture will touch practically every recognized branch of agricultural investigation. Its progressive development would seem to fall into four major divisions, which in their logical order are:

1. The application of electricity as a source of energy to present farming practices.
2. The development of new practices made possible by use of electricity, including the more complete processing of products.
3. The development of unused natural resources on the farm.
4. The staggering of industrial operations with farm operations to secure constancy as well as size of profitable load.

This paper is limited to present farm practices, since it appears most logical to meet present requirements first and to study the requirements of new practices as the need for their development becomes evident.

The work so far has suggested in a broad general way the possibility of employing electricity as a source of energy in the following very general agricultural practices at present in vogue in different types of agriculture:

1. House lighting.
2. House heating
3. Cooking
4. Food preparation, including meat curing.
5. All mechanical operations requiring power, including belt and shaft work and field operations.
6. Field and truck crop production.
7. Animal production, including feed curing and water heating.
8. Dairying, including milk sterilization and pasteurization.
9. Poultry husbandry and egg production.
10. Orchard practices, including heating.
11. Combating insect pests and hail.
12. Drainage and irrigation pumping.
13. Miscellaneous practices.

HOUSE LIGHTING.

Everything indicates that electric lighting, whether of farm or city dwellings and premises, is a well established and more or less economical practice presenting advantages as to convenience, economy of time, cleanliness, and safety from fire hazards of such a degree as to leave little room for argument against it. From the standpoint of research or investigation, no problem exists for all practical purposes except the purely electrical one of possible improvement in illuminating detail.

The problem presented by electric lighting on the farm seems to be one purely of economics. The lighting load is fairly constant the year round, but there is ample evidence to indicate that it is not by any means sufficient to justify general rural electrification. European experience (1) indicates that the lighting load in buildings is usually proportional to the size of the farm. Experience in the Province of Ontario, Canada (2) indicates that the distribution of electrical energy in rural districts must meet at least eight main classes of service, in each of which lighting is included as a necessary incidental to build up the total load but always dependent upon other service to justify it. Experience in an Indiana county (3) in which a rural electric system supplied electric light and power to 100 strictly farm customers from a central station showed the dependence of the electric light upon other loads to make it economically feasible. Experience in a more or less thickly settled rural community of Vermont (4) showed that electric lighting cost 15 cents per kilowatt hour up to an energy consumption of 20 kilowatt hours per month before a reduction in rate was economically feasible. On the other hand, data from 21 electrical substations in Denmark (5) showed that with proper proportions of lighting and motor service loads and correspondingly proportioned rates cooperative central stations could be made profitable.

HOUSE HEATING.

The heating of houses by electricity is not by any means a well established practice even in cities, the objection being that it is generally too expensive. However, it also offers a means of increasing the electrical load, and the available information indicates that it is a convenient, effective, clean, and relatively safe means of heating. The fact that it is an expensive method of heating houses as compared with other methods would suggest lack of perfection of detail of the heating apparatus itself as well as inadequate knowledge as to proper manipulation and use. That it is a generally impractical method of heating at present is indicated by the results of experience by the U. S. Reclamation Service (6) on its Minidoka irrigation project. It was found that when using power supplied by the project generating station, electricity at $2 per month per kilowatt will compete with coal at $8 per ton with an average season for heating of from 5 to 6 months. The general conclusion was drawn, however, that while electric heating is sometimes justified as a by-product load, it will rarely if ever be economically feasible to develop electricity from water power for the prime purpose of using it generally to heat buildings, where fuel can be obtained at reasonable prices.

In spite of the unfavorable evidence regarding the use of electricity for heating, this practice obviously offers a problem worthy of consideration. The heating load will undoubtedly add considerably to the total farm load, thus tending to lower the rate for current. The fuel problem is getting to be a serious one, and the time may come when electric heating for at least part of

the year will of necessity receive serious consideration in some localities. Presumably the problem is one largely of the perfection of heating element and of general manipulation and offers an opportunity for interesting electrical equipment research, as well as agricultural engineering research.

COOKING.

Past experience has shown that cooking with electricity is in general not a very economical procedure. However, electric cooking offers another opportunity for farm consumers of electricity to increase the total electrical load. While the fuel situation may be good in some instances as far as cooking is concerned, it is certainly becoming a pressing problem in many localities. The development of the economic use of electricity for this purpose therefore seems worthy of consideration.

The problem in electrical cooking seems to be twofold, the first being one for the attention of the food and cooking specialist and the second being one of the perfection of detail of the cooking apparatus itself for the attention of the engineer. Obviously the work of the food specialist must come first in order that the exact requirements for the optimum cooking of different foods may be determined to serve as a basis for the perfection of the cooking apparatus and its proper manipulation.

An analysis of the electric cooking load of a central station in southern California (7) supplying over 3,000 electric ranges, of which 95 per cent are in private houses, showed that electric cooking service tends in the long run to conserve both food and fuel. On the other hand, studies of electric ranges at the Kansas State Agricultural College (8) showed that electricity even at 3 cents per kilowatt hour is an expensive form of fuel for cooking as compared with artificial gas at $1 per 1,000 cu. ft. or coal at $8 per ton, costing approximately 100 per cent more than by use of either of these fuels. Thus it is evident that locality and environment are factors for consideration in the development of a profitable electrical cooking load. Undoubtedly where artificial or natural gas is cheap and easily available, it is much more difficult to make a favorable case for electrical cooking than where the same condition exists for electrical energy.

The problem is perhaps more typical and unbiased in localities where neither electricity nor fuels have any initial advantage. For instance, tests were conducted at the University of Missouri (9) with three commercial and several specially constructed experimental electric ovens to determine the amounts of energy consumed in cooking and the best methods of preparing different foods for the electric oven. The results showed that when baking bread, biscuits, etc., the energy lost when the door of an electric oven was open for 15 seconds at an oven temperature of 392° F. amounted to 12 watt hours. The most economical temperature for preparing rare and medium rare roasts was found to be 100° F. and for well done roasts 120° F. The best range of oven temperatures for baking biscuits was found to be from 200 to 240° F. When starting with the oven at the required temperature, the energy necessary for baking biscuits was found to be practically the same for all oven temperatures. If it was necessary to heat up the oven from the room temperature, the most economical oven temperature was found to be the lowest which will give satisfactory results, that is about 200° F. The best range of temperatures for baking a small sized loaf of bread was found to be from 180 to 240° F.

When starting with the oven at the required temperature the most economical temperature for baking bread was between 220 and 240° F. When preheating was included the most economical temperature for a small sized loaf of bread was between 200 and 215° F. The best range of temperature for sponge cake was between 170 and 190° F. As a general proposition, it was found that a heating element in the upper part of the oven is necessary to get the best results for baking at the higher temperatures. It was further found that, on the basis of electricity at 5 cents per kilowatt hour and allowing an interest and depreciation charge of 25 per cent, the most economical thickness of kieselghur insulation for domestic use is from 3 to 4 inches.

English experiments (10) on electric cooking showed that the loss in weight of different kinds of meats was apparently less with electric cooking than with gas or coal-fired cooking and the flavor of the product was vastly superior, both being due apparently to the more flexible and precise control of the electrical heat. Studies in Australia (11) on the development of economical electric cooking apparatus, including ovens and hot plates, showed that nichrome is the most satisfactory material for the wires and green Australian mica is the best material for the insulator and support for heating units. Slag wool and flaked mica were found to be the best thermal insulators for oven construction.

It is thus plainly evident that the building up of an economical and profitable electric cooking load is not a matter merely of installing some kind of commercial electrical stove on every farm and doing all cooking therewith. Comparative tests of gas and electricity for cooking (12) under identical conditions with an arbitrarily selected commercial electric stove showed, for example, that the electricity was about 4.5 times as costly as gas for cooking various meats, and about 6 times as costly for heating water. Similar tests in England (13) gave almost identical results. Obviously then, the development of a profitable electric cooking load must begin with something more fundamental than mere installation of the system or even with comparative tests of different commercial types of electrical cooking apparatus. The food specialist must determine the ranges of temperatures and other conditions for the best and most economical cooking of different foods. With this information as a basis, the engineer must develop electrical cooking apparat which, with proper manipulation, will satisfactorily meet the cooking requirements with a minimum loss of heat and the most economical utilization of electrical energy.

FOOD PREPARATION AND MEAT CURING

Some phases of food preparation are closely allied to cooking as far as the building up of a rural electrical load is concerned. Such practices as the canning of fruits and vegetables, for example, and the making of preserves and jellies, all of which involve the use of cooking heat, might be included in the building up of an electric cooking load. As in the cooking of foods, it is necessary to determine the exact requirements for heat and energy in the preparation of such canned foods as a basis for the economical development and operation of the electrical apparatus required. Much work has already been done by home economists and nutrition experts of State and other institutions on the preparation of such foods as canned fruits and vegetables, preserves and jellies, and even canned meats, and considerable data should be available regarding the temperature amounts and ranges required in such processes.

The dehydration of fruits, particularly in the large fruit-producing sections, apparently offers another opportunity for the building up of a profitable electrical load, especially in view of the susceptibility of electrical energy to precise manipulation and control. The work at the California Experiment Station (14) brings out in particular some of the important requirements of proper fruit dehydration. The work of the committee on the manufacture of farm products headed by Professor Fletcher (15) brought out the importance of securing more fundamental information regarding the best conditions of temperature, moisture, ventilation, etc., to maintain for the dehydration of various fruits, the factors governing which are numerous, extremely variable, and difficult of exact measurement and control. The problem is clear cut as far as the building up of a profitable electrical load is concerned.

The use of an electric current in meat curing has been found to offer possibilities as a process and incidentally as a means for building up rural electrical load. Experiments are on record (16) which indicate that the passage of an electrical current through a vat containing meat in pickle is an effective curing process. Further experiments (17) showed that meat cures more rapidly than by the usual process when it is placed in pickle in vats containing systems of electrodes at each end, forming poles from which an electric current passes through the brine and meat, alternating from pole to pole. Other experiments on this process (18) indicated that the sodium chlorid in the brine is dissociated by the electric current and recombined in the meat, forming sodium hypochlorite, thus bringing the meat into contact with a solution of a strong antiseptic. Evidently much investigational work is necessary before this process is perfected or even its feasibility established.

MECHANICAL FARM OPERATIONS.

The use of electricity as the source of energy in the large number of belt, shaft, and direct drive, and traction jobs around the farmhouse and yard and in the field offers perhaps the biggest opportunity for the building up of a substantial and economical rural electrical load. These jobs are so numerous as to make it impracticable to discuss them all in this paper. The power requirements of many of them are so well known and so nearly the same as to offer practically no problem from the standpoint of research or investigation. The work of Duffee and Palmer at the University of Wisconsin brought much data of this nature to light (19). Other studies reported to the American Society of Agricultural Engineers (20) on small motor applications for farm work showed, for instance, that 1 cent's worth of electricity at 10 cents per kilowatt hour will operate a 6-pound flat iron for 15 minutes, drive an electric vacuum cleaner long enough to clean 450 square feet of carpet, lift 100 gallons of water 100 feet, keep a heating pad hot for from two to three hours, or run a sewing machine for two hours, a 12-inch electric fan for two hours, or a buffer and grinder for 1¼ hours. These and other small motor uses apparently offer little opportunity for further development along economical lines except perhaps improvement in minor mechanical detail.

While these mechanical operations using small standard motors would seem to offer no particular problem when the larger belt, shaft, and traction operations are taken into consideration, the problem is such as to be no longer susceptible of solution by belting a standard motor to existing power machinery.

This point has been brought out forcibly in studies of the use of electrical energy in agriculture on the European Continent (1). The limited seasonal use of much of the machinery and the extremely variable power requirements of machinery for different operations, and in some cases for the same operations, are most important factors adding to the complexity of the problem. The work at the Wisconsin Station on silage cutters, in which power requirements, capacities, and best operating speeds varied widely, serves as a striking example of the problem confronting those who propose to use electrical energy generally for this class of work.

Perhaps one of the largest possible uses of electrical energy in mechanical operations would be in field work such as plowing, cultivation, etc. The load on such work would extend practically throughout the growing season and might be extended further if electric tractors and trucks were developed suitable for farm hauling conditions. In this connection the problem of direct electric drive for traction operations on the farm seems to lie in the development of tractors employing electric motors which are fed either indirectly by cable from a transmission line or directly by a storage battery. The problems in either case have apparently never been solved with any marked degree of satisfaction.

Some work has been done/in both this country and abroad on the development of electric tractors fed by cable. Some such work was done at the California Station some years ago (21), and it is understood that work along similar lines is still in progress at that station. The original experiments demonstrated, by what was considered to be a crude experimental machine, that the soil could actually be cultivated by electric power and that there were at least no fundamental obstacles. A light machine was found to be desirable for garden work owing to the ease of handling and the reduced power consumption. The overload capacity of an electric motor was found to be an important feature in its favor for such work. No information is available as to the present status of this work. The Alabama Station is also planning to undertake developmental work along this line.

Studies conducted in Sweden (22) have resulted in the development of a system of cultivation by means of which an electric tractor with an attached plow and overhead electric cable winding on a drum is used. The field is divided so as to reduce the distance through which the plow has to be driven along the headlands to a minimum, and an open furrow is left midway between two ridges. During a short test a rubber insulated cable showed no signs of wear, while during a long-time test a cable under stress was drawn over pulleys at the mast and over a part of the cable drum for a distance of about 4,600 miles without being ruined. Much is apparently yet to be learned before this type of tractor can be made a success.

Experiments in France (23) with various systems of power plowing using electricity as a source of power indicated that tractors are not essential for deep plowing. The windlass and cable method using a stationary source of power at the end of the field was found to be equally effective and to use cheaper and more durable equipment. However, while the minimum horsepower theoretically necessary was about 30, the actual minimum necessary horsepower of an outfit was about 60 in order to provide a sufficient factor of safety for roots, stones, and other losses. In fact, electric windlasses built for plowing service generally are capable of from 75 to 100 horsepower, such machines being able to plow from 8.5 to about 15 acres per day of 12 hours.

When considering power required and accomplishment, such outfits in their present stage of development do not compare very favorably with our light and rather flexible internal-combustion tractors developing relatively much less power. Further experiments in Germany (24) with similar outfits showed that while plowing in this manner with a gang plow may be a profitable operation, it can not be so unless fitted into a general scheme of profitable utilization of electricity throughout the year. Data from other farm experience in Europe (25) showed that the first cost of a practical electric plowing system of this type averages about $10,000. On the other hand, Italian experiments (26) have shown that electrical power for plowing when available at from 3 to 5 cents per kilowatt hour is considerably cheaper than steam or animal power.

It is thus plainly evident that the development of an effective and economical tractor or plowing outfit has never proceeded much beyond the preliminary stages. The variable results so far obtained would indicate that not enough is yet known about plowing and cultivating and the machinery suitable therefor to form a sound basis for the final development of electrical traction plowing apparatus. Everything indicates that such development must follow the elucidation and establishment of the fundamental principles of soil dymanics and the development of corresponding tillage machinery if it is to provide a profitable addition to the farm electrical load. There are so many unknown factors of soil dynamics affecting tillage and other factors such as speed of operation, friction, impulsive traction, etc., all of which will influence the development of electrical power units for cultivation as to make it seem quite impractical at this time to undertake the manufacture of electrical tractors for tillage operations except for experimental use.

In this connection, attention may well be drawn to recent studies conducted at the Rothamsted Experimental Station in England (27) on an electrical method for the reduction of draft in plowing. On the basis that an appreciable fraction, estimated roughly at one-third, of the total work done in plowing is expended in overcoming the frictional forces between the moldboard and the soil, an electrical method of reducing the friction on moist surfaces which depends upon the phenomenon of electroendosmose exhibited by moist soil was developed. It was found that, by virtue of the negative charge of the soil colloids, water will move through moist soil toward the negative electrodes under the action of an electric current. It was found both in the laboratory and in the field that if a current was passed through the soil having the moldboard of a plow as the negative electrode, the film of water formed at the soil-metal surface acted as a lubricant and reduced the plowing draft. Especially striking reductions in frictional losses were obtained by the use of such current in laboratory experiments in which a slider consisting of a weighted metal spatula was drawn over the surface of a slab of moist soil in a metal tray by means of a thread passing over a pulley to a scale pan. Preliminary tests in the field demonstrated that the draft of a plow could be reduced by applying the current between the coulter and the moldboard. While the magnitude of the reduction obtained with this arrangement was not great enough to have an immediate practical value, the method is considered to offer marked possibilities for further development along practical and profitable lines. Thus if practical electrical plowing apparatus were available, these experiments would suggest the possibility of developing a twofold profitable use of electricity in plowing operations.

Much the same general indecision prevails throughout results of experience on the use of electricity in other larger power operations of the farm. Experiments in Ontario, Canada (28), shown that motors developing from 1 to 8 horsepower will do all of the ordinary power work of the farm, while for the heavier work such as threshing, silo filling, feed grinding, etc., at least 20 horsepower motors are required. Experiments already reported to the American Society of Agricultural Engineers (20) demonstrated the variable power requirements of different operations and machines. At the same time it was shown that a feed grinder could be operated at 650 revolutions per minute by a 5 horsepower motor when grinding corn with a power consumption of 0.433 kilowatt hours per bushel and by a 15 horsepower motor under similar conditions with a power consumption of 0.411 kilowatt hours per bushel. Another significant finding was that a small thresher having a 28-inch cylinder and a 42-inch separator could be driven by a 15 horsepower motor with power consumption of 2.62, 2.36, and 2.7 kilowatt hours per ton of oats, barley, and wheat respectively. The results of the threshing experiments in Iowa (29), in which an outfit consisting of a 30 horsepower, 220 volt, 60 cycle, single phase motor was used with a threshing machine having a 32-inch cylinder and a 54-inch separator on barley separations, showed that with electricity at 5 cents per kilowatt hour the operating expense was 25 per cent less than that by steam engine. About 6.5 bushels of barley were threshed per kilowatt hour of power used.

On the other hand, experiments in Germany (30) showed that steam engine power was essentially cheaper and more efficient than electrical energy for threshing. Other German experiments (31) gave similar results generally in favor of steam power. However, French tests (32) demonstrated the superiority of electrical energy over horsepower for threshing in both cost and accomplishment. German experiments (33) confirmed these results, indicating that the work accomplished by electrical motors in threshing was nearly 17 per cent greater than that by horsepower owing largely to uniformity of operation.

Experiments in a rural community (34) on the comparative values of steam power and electrical energy for silo filling showed that the daily rent, including the cost of the energy consumed by a 15 horsepower electric motor with transformer mounted on a truck, was considerably less than the expense of using a steam traction engine. The average energy required per ton of silage cut and elevated was 1.17 kilowatt hours. Some question may be raised as to the general applicability of these results when the variable power requirements, speeds, and capacities of different silo fillers are considered, especially as indicated by the Wisconsin experiments. It would seem that before electricity can be applied most effectively and economically to silage cutting and elevating, more must be learned about the power and speed requirements of these processes as a basis for the development of the machinery involved along more rational and standardized lines.

There are many other mechanical farm operations of medium power requirement which have been successfully performed with electric motors such as ice harvesting (35,36), operating refrigerating apparatus, binder driving, etc. Records of such experience also exist, indicating that electric power does not compare favorably with other forms of power. For example, experiments conducted in Germany (37) on the efficiency and economy of steam and internal-combustion engines and electric motors for a large number of medium power mechanical farm operations showed that the internal-combustion engine was the most efficient type of power for the smaller operations under actual working conditions.

The steam engine usually gave better results for the heavier operations. The results in general were more or less unfavorable to the use of central station electricity on farms for this purpose. In the face of these results, experiments conducted at the University of Missouri (38) led to the conclusion that the convenience and ease of operation of electric motors are such as to make their daily use profitable in many farm operations.

A careful consideration of this brief summary of significant but nevertheless more or less conflicting results would seem to indicate that the use of electric motors generally in practically all mechanical farm operations is a quite promising possibility, which incidentally also offers a quite considerable field for the building up of the total electrical load. However, the general conclusion drawn from extensive European experiments (39) that any farm machine which revolves or has revolving parts can be operated by electric motor more effectively and economically than by any other means is undoubtedly extremely optimistic with reference to the present status of the use of electricity in agriculture. On the other hand, when it is considered that this conclusion is based upon a proposed fundamental study of the requirements of each process and machine as a basis for the gradual and rational application of electrical power, it would seem to sound somewhat more reasonable.

Owing to the attendant power losses, it would seem that success in this undertaking lies largely in the development of the use of smaller power units in agricultural operations. This is borne out by experimental data already available and strongly indicates the ultimate necessity of overhauling practically all of the larger power operations with a view to effecting the application of smaller power units operating over longer periods of time. This will involve a complete study of the fundamental requirements of all mechanical operations to determine how far such a procedure can be extended and may mean the complete redevelopment of a number of agricultural machines. The necessity for such a study of process requirements and the development of corresponding machines is indicated anyhow in the case of many machines such as silage cutters, tillage machinery, and others which show a broad variation in operating characteristics among the commercially available types. It seems evident, therefore, that the building up of a profitable electrical load in connection with mechanical farm operations must inevitably be the result of very intensive research and investigation leading to the very gradual development of processes and machines.

CROP PRODUCTION.

The use of electricity in crop production, entirely aside from the mechanical operations involved, has held the attention of scientists in this and other countries for several decades. In fact, there is available a history of research involved in the gradual development of so-called electroculture extending back over a period of at least 40 years.

An effort has undoubtedly been made in this work to get at the fundamentals of the process. The investigators have obviously been less interested in the building up of an electrical load than they have been in establishing the nature of the stimulation of crop growth and yield by electricity and in making a profitable application of the process.

The work on electroculture so far is, however, obviously quite incomplete and has been productive of more or less unsatisfactory and in many cases contradictory results. On the other hand, as it has progressed through a very gradual but nevertheless altogether normal development, it has indicated certain very definite lines of fundamental study, each of which may have a more or less marked influence on the success or failure of the process.

These lines of study may be grouped broadly under stimulation by electric light, by overhead atmospheric electrical discharge, by soil electrification, and by electrical seed treatment either direct or indirect. While no attempt will be made to give the complete history of each line of work, attention will be drawn to a sufficient number of typical instances to indicate general results and tendencies.

Effect of electric light on crop growth.--A long series of studies were conducted at the New York Cornell Station (40) on the influence of the electric arc light upon greenhouse plants. These showed as a whole that the electric arc light promoted assimilation, hastened growth and maturity, was capable of producing natural flavors and colors in fruits, and increased the production of flowers. Periods of darkness were found to be unnecessary to the growth and development of plants. A continuation of this work (41) in which an arc light with a clear glass globe was hung above the greenhouse showed that lettuce was greatly benefited, radishes, beets, and spinach were somewhat benefited, cauliflowers tended to grow taller and make fewer and smaller heads, while with endives the results were negative. The electric light did not appear to determine or modify the periods of growth of lettuce. Further studies (42) showed that a naked electric arc lamp in the greenhouse greatly injured cauliflowers growing near it, but exerted little influence beyond 10 feet. Electric light transmitted through glass screens of different colors exerted decided influences on radish and lettuce plants early in their growth, which tended to disappear as the plants approached maturity. Tests of the effect of incandescent electric light on plants in greenhouses at the West Virginia Station (43) showed that the incandescent light had a marked effect upon greenhouse plants, especially in foliage growth for plants such as lettuce. It induced objectionable early running to seed in such plants as spinach and endive. Proper watering appeared to be more important for radishes, beans, and cuttings than improper watering with electric light. The results were more marked the stronger the light. There was some doubt as to the economy of this process.

Austrian experiments (44) on the influence of varying the intensity and duration of illumination on such crops as beans, mustard, and wheat showed that continuous illumination with carbon lamps of from 25 to 100 candle power lights accelerated growth. German experiments (45) showed that seeds germinate earlier under electric light and that bulbs, beets, beans, flax, and other plants produce seed earlier. Other experiments in this country (46) indicated the superiority of the ruby light for radishes and violet light for lettuce, especially under high frequency.

These experiments as a whole indicate that artificial illumination of crops by electricity offers considerable possibility. Apparently the advantage gained lies mainly in hastened maturity, which is of course a disadvantage in the case of some truck crops. Incandescent lights seem to be somewhat superior to arc lights and apparently the color spectrum has a bearing on the matter. It would seem that the problem now is to determine

those plants actually benefited by such treatment, the nature of the benefit, their specific requirements for light to produce optimum growth and yield, and the degree of and color of illumination giving the most profitable results as a basis for developing this practice as a part of the rural electrical program.

Effect of atmospheric electrical stimulation on crop growth.--The results of experience in the overhead electrical treatment of crops have been many and varied. Early experiments at the Massachusetts Station (47) gave results generally in favor of overhead electrification of crops. French studies (48) showed that electrical currents have a direct and indirect influence upon plants. Under the direct influence the protoplasmic membrane loses its semi-permeable nature and permits the electrolytes to escape from the cells. The albuminoid systems of the cells behave in a similar manner, their ions escaping from the cell and distributing themselves toward the positive or negative electrodes in proportion to their electrolytic nature.

Experiments in this country with vegetables (46) showed that plants subjected to high frequency electrification produced greater increases than under any other type of treatment. On a large scale such treatment increased the yield of all garden crops except beans and peas. Similar results were obtained in English experiments (49), it being found that with a few exceptions leguminous crops were adversely affected.

Pot culture experiments conducted in Germany (50), in which a current of from 35,000 to 40,000 volts was taken from a machine and made to jump a distance of 15 cm. from a copper wire point suspended over each pot to an upright copper wire point in the center of the pot, showed that when the suspended point was connected with either the positive or negative pole the current had an injurious effect upon rye and winter barley when applied during a period of from 16 to 20 days at stated intervals. Reducing the charge increased these crops, especially when the copper points in the pots were removed. In open air experiments, the atmospheric moisture interfered with uniform discharges and resulted in yields varying from 5 per cent increase to 17 per cent decrease. When the discharge took place from points placed 13 cm. above a water surface the evaporation was from 5 to 10 times more rapid than from an untreated surface.

Bohemian experiments (51), in which insulated wire nets stretched at a height of from 12 to 15 feet above growing beets were subjected to an electric current of from 50,000 to 70,000 volts and from 0.7 to 0.8 milliamperes, resulted in noticeably increased crop production and differences in chemical composition of the product, which were attributed to a direct influence of the electricity upon the soil rather than upon the plant. German experiments (52) with an electrical brush discharge of high tension showed no decided beneficial effects upon the growth of several cereals. Previous beneficial results were attributed largely to an increase of transpiration produced by the electrical wind attending the brush discharge.

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Experiments (53) on the application of a voltage stress to the atmosphere around plants caused good results only when the stress was applied on cloudy days and at night. No difference in stimulative effect was found when using the ground as a positive or a negative, and there was some tendency to show for all plants a curve approximating a straight line within certain limits, the slope of which was different for each plant. The general conclusion was drawn from these experiments that indirect stimulation of the root or plant increases the functional activity of the organs if they are far enough from the point of application of the stimulus to avoid the effect of direct stimulation. Although the immediate effect of direct stimulation was to retard growth, it increased the internal energy of the plant and the after effect was to increase the growth rate.

Other studies conducted in England (54) on the respiration of plants under various electrical conditions showed that an increased crop or earlier maturity may be the result of electrical treatment. Direct currents of a density of from 10^{-6} to 10^{-4} amperes had no effect on the respiration of peas other than that due to accompanying changes of temperature. Overhead discharges producing a current of density less than 3×10^{-6} amperes had no effect on respiration. Electrification had no influence on respiration in the field either, so that any growth acceleration is due to stimulation of other plant functions than respiration. Further studies (55) in England on the distribution of overhead electrical discharges showed that the strength of the discharge from an overhead wire network at a high potential is a variable quantity, depending upon the mobility of the carriers of electricity and on the wind velocity. Measurements of potential gradient and of current density agreed in showing that the effect of the discharge is not limited to the area under the wires. Further studies on this feature (56) showed that screens surrounding electrified areas must be higher, the carrying wires lower, and the plats more completely isolated by screening and by location with reference to prevailing winds. Separation of experimental from control plats by a distance of at least 100 yards was indicated by other studies (57).

German experiments (58) on the influence of high frequency currents on plants showed that large increases in growth and chlorophyll formation of several common vegetables were due to the oscillating field of an alternating electric current of very high potential and rapidity of oscillation and not to the heat generated by the current.

Russian experiments (59) showed that while atmospheric electrical influence increased crops, especially when employed during the hours of sunlight, its practical employment was not warranted.

Additional English experiments (60) showed that overhead electrification markedly increased crops such as oats, especially when the intensity of the discharge was increased by lowering the wires, by reducing the distance between wires, and by reducing the thickness of the wires.

Experiments in Scotland (61) on the overhead application of a high tension electrical discharge to oats, barley, hay, potatoes, turnips, and swedes grown in rotation during a period of 5 years failed to produce sufficient increases in yield to repay the cost of the treatment.

Three years' studies at the Missouri Botanical Gardens (62) on the overhead electrical stimulation of truck crops showed increased yields and earlier maturity, but indicated that before any definite practical application can be made it will be necessary to establish (1) quantative measurements of the electrical discharge, (2) the different stimulating actions on plants at different stages of life, (3) the effect of intensity of the stimulus and the time of application, and (4) the length of time elapsing between the application of the stimulus and the occurrence of the stimulating effect.

Experiments in South Wales (63) demonstrated the effectiveness of a network of No. 24 steel wire with meshes 6 ft. square and straight wires 9 feet apart suspended 5 feet and 2 feet above ground and through which was passed a current varying between 30,000 and 39,000 volts in increasing the potato crop on heavy loam soils.

Experiments conducted at the Kentucky Station (64) showed that in general smaller crop yields were obtained on electrified plats than on nonelectrified plats with the exception of potatoes.

Pot experiments at the Rothamsted Experimental Station in England (65) showed that an overhead electrical discharge accelerated reproductive growth of barley apart from vegetative growth. Field experiments indicated that with overhead wires set a distance apart not much in excess of their height fully half of the current supplied to the wires reached the crop. Further pot experiments at Rothamsted (66) indicated that alternating current is usually as effective or more so than direct current, and that upward current through the plant increases growth the same as downward current.

This summary, while incomplete and indicative of contradictory findings, shows the numerous lines along which possibly profitable investigation may be undertaken on the overhead electrical stimulation of crops. While obviously the main object of most of this work has been to determine the nature of the influence of overhead stimulation on plant growth phenomena, it would seem that too little attention has yet been given to the actual requirements of optimum growth and yield and the corresponding amounts, rates, frequencies, manner of application, and other characteristics of overhead electrical stimulation which may promote such optimum growth conditions.

Electrical stimulation of crops through the soil.--The stimulation of crop growth and yield by means of electrical currents passed through the soil has not been investigated so extensively as has the atmospheric discharge method. Nevertheless, it apparently offers an opportunity for development into a possibly profitable process which may add considerably to the electrical load. It is of course merely another kind of electroculture, and its economic value is yet to be established.

Early experiments at the Utah Station (67) showed that electricity conveyed by a network of wires 10 inches deep in the soil apparently markedly increased the yield of several field crops, but reduced the yield of turnips.

Experiments at the Massachusetts Station (68) in which noninsulated copper wires connected with a dynamo were placed 2 inches below the surface of rich soils, showed a favorable influence of such electrical stimulation on the yield of parsnips, radishes, carrots, lettuce, and turnips, while the yield of sweet German turnips and Egyptian beets was decreased. The ripening of tomatoes was hastened by such stimulation.

Numerous experiments in Germany (69) on the influence of electric currents on crops and soil organisms showed on the other hand that a constant current is injurious to both germination and development of plants. This influence was most marked immediately between the electrodes, and tension, current strength, duration, soil conductivity, and general soil composition as well as electrolysis seemed to be factors influencing the degree of injury. In this connection French experiments (70) showed that the influence of an electric current upon plants was quite different on soils of varying chemical composition.

Experiments at the Massachusetts Station (71) showed that apparently the effect of positive and negative stimulation of plants offers a mechanical explanation of the positive and negative galvanotropism in roots. When plants were grown between positive and negative electrodes, each electrode exerted a characteristic influence on the root, and that surface of the root nearest the anode was affected according the the nature of the stimulus on that side. When weak currents were used the positive current gave the greatest stimulation to those cells on the anode side of the root and induced bending in the root toward the negative pole. On the other hand, strong positive currents induced bending toward the anode, due to retardation or injury of the cells on the side of the root toward it. It appeared that increasing the electrical tension of the atmosphere either by the use of static charges or by the use of high tension wires caused a greater degree of stimulation than passing the current through the soil. Alternating currents had a greater stimulating effect than direct currents.

Somewhat in contradiction to these results, western experiments (53) showed that a direct current passing through the soil containing the seeds or roots of plants caused a gain in root structure and the electrified plants after transplanting were more hardy and grew faster than the nonelectrified. Similar tests with alternating current gave positive results only under very low power values.

The apparently contradictory nature of some of these results would seem to indicate the importance of learning more about the requirements of optimum plant growth in different kinds of soil. Evidently soil composition has an important influence on the stimulation of crops by electricity, and the nature of the current whether direct or alternating seems to merit consideration.

Treatment of seed and seedlings by electricity.--Work on the electrical treatment of seeds has apparently been divided into electrochemical treatment and attempts to effect direct stimulation by electrical currents. The former process consists essentially of passing a current of electricity through a solution of common salt or some other compound in which the seed is immersed. Experiments have been conducted on this process in Canada (72), in England at the Rothamsted Experimental Station (73), and at the Arlington Experimental Farm in the United States (74).

Most of these experiments did not bear out the claim that such treatment increases the yields of such crops as wheat. The Arlington Farm experiments especially showed no benefit or profit resulting from such treatment. In fact, the grain yields from treated seed averaged 1.1 bushels per acre less than those from untreated seed. The purpose in mentioning this process is merely to show its status as a rather unpromising possibility as a source of a profitable electrical load.

The direct stimulation process, however, seems to offer a slightly more favorable prospect. British experiments (75), for example, showed that direct currents varying from 0.175 to 9 milliamperes produced a decreased respiration of germinating seed of from 20 to 30 per cent. Where the current was rapidly reversed the lower current produced an increase in respiration, while the higher currents decreased it. The best results were obtained by connecting the positive pole of an electric machine with a platinum loop just above the seeds, the latter being connected with the earth and thus passing a discharge into the seeds.

French experiments (76) indicated that a continued electric current is decidedly injurious to the germination of seed.

These experiments as a whole, while not very promising, indicate the possibility of developing the use of alternating currents of low intensity for the stimulation of seed germination. It would seem that more should be known regarding the requirements of proper germination to be used as a basis for such development.

So far there seems to be more or less certainty that electricity has a favorable influence on the growth and yield of some crops under certain conditions. The mode of action of such stimulation whether from illumination, atmospheric discharge, or soil treatment is yet obscure. Until that mode of action is made known for the proper crops under specific conditions the resulting electrical load can never be developed with any assurance that it will eventually be a profitable one. Everything indicates that individual investigations on the subject so far have been too cursory. It would seem that there should be a greater systematic variation of conditions and especially of the electrical conditions.

ELECTRICITY IN ANIMAL PRODUCTION.

While apparently very little investigational work has been undertaken on the use of electricity in the processes specifically related to livestock production, it would seem that this field is worthy of consideration at least as a possible source of a profitable electrical load.

The science of ventilation of animal shelters is rapidly developing and should eventually offer a field for the use of electricity in mechanical or forced ventilation where beef, pork, or dairy stock are handled on a large scale. The use of electricity for the artificial lighting of feed lots to increase the gains in meat stock has also been advanced as a possibility. Obviously more study by animal experts is necessary to determine more definitely what are the light requirements of animals corresponding to optimum feeding conditions. It would seem that this scheme offers its greatest possibilities in winter feeding.

The preservation of succulent feeds and the curing or drying of such feeds as hay and grain by electricity suggests other possibly profitable uses of electricity in matters relating directly to animal production. More or less recent studies on the preservation of green feeds by electricity have been conducted by the California Station (77). In this work, alfalfa and foxtail silage treated in three 30-inch tiles with a 220 volt alternating current of electricity for one and two months was in good condition upon opening, except for a little decay at the top and around the walls of the tiles. Cattle ate the silage without waste. While this process is apparently so far not very satisfactory

or profitable, the results obtained are obviously of such a nature as to warrant further study. Over one hundred instances of apparently successful electrical silage preservation are on record in Germany (39). This experience has shown that objectionable bacterial action is arrested by the electrical treatment, thus better preserving the fodder. Each silo has a grounded electrode fixed at the bottom and a live electrode is placed on top of the freshly cut green silage. From 24 to 48 hours of electrical treatment are required and each ton of fodder requires from 13 to 20 kilowatt hours of electricity.

Hay curing by electricity has been successfully accomplished in experiments conducted in Scotland (39) in localities where the conditions for good hay curing are frequently if not almost constantly unfavorable. Stacked green grass was dried by air blown by an electrically driven fan. The rate of drying was inversely proportional to the amount of moisture suspended in the atmosphere no drying taking place when the atmosphere was saturated. The curing process required about 30 hours during which 60 per cent of the weight of the grass was evaporated. Hay cured in this manner had a better appearance and smell than naturally cured hay, and its nutritive value was greater. The profitableness of the process was apparently not established, but the results obviously warrant further attempts to develop the process into a profitable one. It should be noted that the Alabama Station has such work under consideration.

The use of electricity for the maintenance of proper temperatures of the drinking water for stock, especially in winter, seems also worthy of consideration. Of course the prevention of freezing would be a big factor, but it would seem that in the development of such a use a study should be made to determine the optimum ranges of drinking water temperatures for different farm animals. Automatic control of such temperatures by electricity would seem to be quite possible.

ELECTRICITY IN DAIRYING.

The processes involved in dairying which require heat and power would seem to offer an opportunity for the development of a quite sizable addition to the rural electrical load. While some experience has demonstrated that electricity may be used in such processes, others have shown that the exact requirements of many of these processes are not quite well enough known to permit an entirely profitable use of electrical energy. German experiments (78) comparing steam and electricity in the work of an average small dairy indicated that electric power must cost as low as 2.5 cents per kilowatt hour in order to give the economy of steam for both mechanical operations and milk and water heating.

Experiments in New Zealand (79) on the use of electricity in five typical milking plants showed that a 2 horsepower motor was sufficient in most cases for machine milking on the prevailing average scale. Tests made in the United States (20) on an 8-machine milking equipment driven by a 3 horsepower motor showed that the power cost was about 2 mills per cow with electricity at 10 cents per kilowatt hour. The average load on the motor was 2.3 horsepower and the vacuum maintained by the pump was 15 inches. The New Zealand experiments noted above showed on the other hand that for average milking conditions a 3 horsepower motor was uneconomical. Subsequent experiments showed that even a 1 horsepower motor would operate sufficient milking machines to deal with a herd of 100 cows. Since a large proportion of the herds range from 10 to 20 cows, a plant capable of milking two cows at a time is all that is required.

The final development in New Zealand is a compact type of machine capable of fulfilling this service and driven by a motor of only 0.25 horsepower. This strikingly illustrates the importance of a better knowledge of economical power requirements in such dairy work as machine milking.

The results of an intensive study of the utilization of power and heat in German dairies (80) to compare the efficiencies of steam power and central station energy showed that under the prevailing operating conditions of dairies central station energy was considerably more expensive than steam. Comparative trials of steam and electric motor power for performing the different operations in dairies in the Dahme district in Germany (81) showed that as a whole the electrical method was more expensive than the steam plant method, although the unit fuel requirement was less. It is thus evident that much is yet to be learned regarding the use of electricity in the heat and power operations in dairying in order to make such use generally profitable.

The flexibility and susceptibility of electrical energy to precise and accurate control would seem to make it a quite desirable form of energy for use in dairying operations such as milk sterilization and pasteurization. British experiments (82) showed, for example, that bacteria in milk were stimulated by the passage of low electrical currents, and where static electricity was used their growth was favored to a considerable extent by a positive charge. On the other hand, where heavy charges were used the numbers of organisms decreased very decidedly. Experiments conducted at the University of Liverpool (83) showed that by the use of a specially constructed electrical apparatus milk could be sterilized without detriment to its nutritive value and tubercle bacilli could be destroyed. Experiments in New South Wales (84) showed that satisfactory results were attained in the sterilization of milk by short exposure to a high tension electrical current. The milk was not unduly heated, no coagulation occurred, and it was possible to sterilize a continuous stream. There was a complete destruction of all colon and allied bacilli and an enormous reduction in bacteria of all kinds. The milk was unaltered in composition and the enzyms were not destroyed. English experiments (85) on the effects of a rapidly alternating current at high potential in milk sterilization showed that disease producing and milk souring bacteria were practically destroyed in the raw product. Further experiments at the University of Liverpool (86) demonstrated that electricity can be successfully applied as a sterilizing agent to milk, with special reference to Bacillus coli and its allies and tubercle bacilli. Similar results were obtained in experiments by the British Board of Agriculture (87). Other experiments (88) demonstrated the effectiveness of alternating current, especially in this process. It thus seems evident that if economy as well as effectiveness can be incorporated in such uses of electricity in dairying practices, a profitable addition can be made to the total rural electrical load. However, everything indicates that more should be known as to the exact result it is desired to accomplish in processes for the sterilization or partial sterilization of milk. Preliminary investigations at the Alabama Station were recently narrowed down to an effort to determine just how far such treatment should be carried as a basis for the development of economical electrical methods for its accomplishment. This would seem to indicate the necessity for more study on the part of dairy specialists, so that more exact requirements for milk treatment can be advanced for the engineers to meet.

ELECTRICITY IN POULTRY HUSBANDRY AND EGG PRODUCTION.

The use of electricity in poultry husbandry and egg production apparently offers another opportunity for increasing the electrical load. Several of the State experiment stations and foreign agricultural institutions have demonstrated the beneficial influence of maintaining proper temperatures in poultry houses, especially in winter, with reference to the comfort, health, and productiveness of the poultry. As far as the optimum range of such temperatures has been determined for specific conditions, it is evident that in some climates artificial heat will be required during parts of the year. The susceptibility of electricity to precise control would seem to recommend its use for this purpose if the exact requirements can be established and the electrical heating can be made automatic. Obviously, however, the facts governing the use of electricity in a profitable manner must be established before the process can be adopted.

A certain limited amount of experience has also indicated the possibility of using electricity as a stimulus to the growth and development of poultry. In experiments conducted in England (89), for example, a chicken house consisting of 6 flats, each large enough to accommodate 75 chickens, was electrified by a large helix of heavily insulated wire wound round it in turns about 6 inches apart. It was found that when the current was applied for 10 minutes every hour during the day there was a mortaility of only 1.5 per cent among the chickens and that they were ready for market in 5 weeks instead of 3 months. In another instance the increase in weight of chickens in the electrified house was about 35 per cent. In still another test electrified chickens were given only two-thirds of the food given to nonelectrified chickens, and after one month the weight per bird was the same.

Experiments in the United States (90) showed that high frequency currents apparently stimulated the blood circulation of poultry by lowering the viscosity of the blood. It was not established whether prolonged electric action increases growth up to maturity or whether its whole effect is to cause the maximum size to be reached sooner. The possibilities of this process are thus plainly evident, although obviously much must yet be learned regarding the nature of the stimulation as a basis for determining the requirements of optimum growth and the best methods of promoting the corresponding conditions by electrical stimulation.

The use of electric light for increasing egg production, especially in the winter months, seems also to be a quite promising process which will involve the profitable use of electricity. Experiments at the Kentucky Station (91) showed a marked increase in egg production during the winter months for both hens and pullets under electric light, although the annual production from hens not under light was slightly greater than from those under light. Similar results were obtained at the Ontario Agricultural College (92) and at the North Carolina (93, 94), Montana (95), and New Jersey (96) experiment stations. Experiments at the New Mexico Station (97) showed that artificial lighting caused a smaller egg production during the winter, although the lighted hens reached the highest point of production and laid more eggs when eggs were scarce. Experiments at the Michigan Station (98) indicated that certain unsatisfactory results may follow too much artificial lighting. Experiments at the California Station (99) showed that birds in pens electrically lighted both before sunrise and after sunset each day went through a heavy molt in the spring. Those illuminated only at the end of the day molted lightly, while those exposed in the morning hours only did not

molt at all. Further experiments at the California Station (100) indicated that the main cause of increased egg production from the use of artificial light in the winter seemed to be the resulting longer time during which the birds were able to eat and exercise. Artificial lighting was found to be inadvisable for breeders.

It is thus evident that while there is considerable disagreement as to proper practice, the results as a whole indicate that artificial illumination results in greater egg production when eggs are scarce and expensive, but does not necessarily increase the total annual egg production. In fact, there is some evidence that the total production is frequently decreased. However, the difference in the price of eggs when they are scarce and when they are plentiful indicates that the process may be made quite profitable. Apparently, however, there is a problem involved which will require the determination of the best kind, periods, and intensity of illumination for different breeds of chickens under different specific conditions.

A final use of electricity in poultry husbandry which seems worthy of development is for heating brooders and incubators. Experiments at the California Station (101), in which a comparison was made of brooders heated by electricity, coal oil, coal, and gas heated hot water showed that the electrically heated brooder was the most economical in labor and fuel consumption when filled to a reasonable capacity. It is worthy to note, in this connection, that the Alabama Station has undertaken a study of the electrical control of the fundamental factors entering into the incubation of hens' eggs. The preliminary analysis has indicated that the variable factors of incubation, the effects of which on the embryo should be studied and controlled between certain optimum points, are temperature, humidity, air flow, carbon dioxid, and other air gases, length of cooling periods, and time of turning.

ELECTRICITY IN ORCHARD PRACTICES.

The greatest use of electricity in orchard practices will probably occur in those operations requiring power such as spraying, cultivation, etc., which may be included under mechanical farm operation requiring power. Another use, the possibilities of which would seem to warrant specific development, is for orchard heating to prevent injury to fruits by late frosts. The importance of the development of practical and economical methods of orchard heating for this purpose needs no emphasis, and considerable work has been done along this line. Experiments conducted by the New Zealand Department of Agriculture (102) showed that the process of overhead electrification had a tendency to prevent frost injury in orchards. Experiments at the Utah Station (103) on the relative merits of heat supplied by electric heaters and smudges for the prevention of frost injury in orchards showed that when electric heaters were distributed about in the open in the same manner as smudge pots are distributed in an orchard, 100 horsepower of electrical energy, when converted into heat in the open air, resulted in a temperature rise of 20° F. with an outside temperature of 70° F. Approximately 14 watts per square foot were required to obtain 1° F. rise in temperature. The results of 15 investigations at other stations agreed in showing that with 100 heaters to an acre, the orchard will remain about 4° F. warmer than the surrounding unheated area. Winds of 10 miles per hour reduced this to less than 1.5° F. On the assumption that the common smudge oils give out 18,000 B.t.u. per pound burned and that a gallon of this oil lasts 4 hours, it has been estimated that these smudge pots develop approximately 6 watts per square foot in raising the temperature of the air in an orchard 1° F.

The use of electricity for this purpose would naturally seem to be out of the question for small orchards. But in the large fruit producing regions, it would seem that the development of such a use for electricity might be most profitable, especially when it is considered that the use usually meets a very pressing emergency which may mean success or failure of the crop for the year.

The problems involved are numerous, and several of the experiment stations, including the California, New Mexico, and Alabama Stations, are or have been interested in solving them. It would seem that more study is needed to establish the ranges of minimum permissable temperatures for various fruits at different stages of early development in different localities to serve as a basis for the development of the most effective and economical means and apparatus for supplying the necessary amounts of heat by electricity. This will naturally involve a consideration of such factors as wind velocity, topography, and climatic conditions

COMBATING INSECT PESTS AND HAIL BY ELECTRICITY.

Entirely aside from the mechanical operation of spraying, there would seem to be a possibility for the utilization of electricity for combating insect, fungous, and bacterial enemies of plants. Relatively little of an experimental nature has been done on such processes and apparently very little is known. However, the U. S. Department of Agriculture Bureau of Entomology and Public Roads cooperating have apparently found a use for electricity in the dusting of cotton fields by airplane in the fight against the boll weevil. Apparently the use of the electricity is made in so charging the poisonous dust particles that they will be attracted by and held in place on the cotton. How great a use of electricity this process entails is not known. In fact, none of the exact details of the process are apparently as yet available. However, the fact that work is being continued would indicate that the process offers quite considerable promise.

As an example of the more direct utilization of electricity for the destruction of insect pests, it has been found by actual experiment (104) that an alternating current of high voltage and low ampereage can be passed through the bark of trees or through soil with the result that the insects or other harmful animal pests with which they are infested are destroyed. It has been found, however, that weak currents (82) may have a stimulating effect on some yeasts and bacteria in solution.

Attention may also well be drawn at this point to the results of a French investigation (105) which showed that a hailstorm closely followed the course of a 45,000 volt, 8 phase transmission line for a distance of 8.7 miles. The observations indicated that the current had some effect in attracting and directing the storm. Further studies (106) indicated the possibility of using this means for protecting vineyards and crops from damage by hailstorms. While more recent studies have thrown some doubt on the value of this process, nevertheless there should be some consideration of its possibilities in the location of transmission lines with reference to growing crops.

DRAINAGE AND IRRIGATION PUMPING BY ELECTRICITY.

There is a record of considerable experience in the use of electricity as power for pumping in drainage and irrigation practices. Naturally the greater part of the experimental work along this line has been done by the U. S. Department of Agriculture Bureau of Public Roads and by the U. S. Department of Interior Bureau of Reclamation. Exact data on such investigational work can best be obtained

from those bureaus. In addition it is interesting to review data from actual large scale experience with this practice. For example, data (107) from 125 electrically driven irrigation pumping plants in the Pomona District in southern California, operating on both deep well and low lift service, show that the cost varied from 2 to 3 cents per kilowatt hour. Other experience (108) with electrical irrigation pumping on an area of 10,000 acres with 69 motor driven pumping plants owned by farmers showed that the cost of energy was less than 1 cent per kilowatt hour as supplied by a central station. It is thus evident that pumping by electricity for irrigation purposes represents a quite sizable electrical load, which may be obtained at fairly low rates in some localities. It would seem that with this load as a nucleus, provided it is a profitable one, the opportunity for building up a profitable total electrical load on farms in certain of the irrigated sections is quite promising.

Drainage in some of the larger districts of the wet and swampy sections requires considerable pumping. Data on first cost and operating expenses of steam and electricity driven pumping stations used for draining agricultural lands along the Illinois and Mississippi Rivers (109) showed that the cost of building a modern electrical pumping station varies from 50 to 60 per cent of building a steam driven plant to do the same work. The total operating expense for electrical pumping stations for drainage district service has been found to be from 10 to 35 per cent less than that of steam stations under the same conditions. Everything indicates that the pumping load in drainage districts in large overflowed sections may be sufficient to justify a large part of the expense of installing transmission lines which may also be used for purely farm service. The importance of solving the problems, if any, which are involved in the development of the practice of drainage pumping by electricity is thus plainly evident when considered in the light of the requirements of general rural electrification.

ELECTRICITY IN MISCELLANEOUS RURAL PRACTICES.

There are many other miscellaneous either farm or cooperative rural practices which might be so developed both scientifically and economically as to make the use of electricity as the source of the required energy a profitable use. Many of these are direct drive power uses while others require heat development. For instance, the rural cooperative laundry movement such as that developed in Wisconsin might be the source of a large and profitable enough rural electrical load as to go a long way in justifying the installation of a transmission line. Cooperative destructive distillation of wood and other wastes and refining of raw molasses such as is under consideration at the Alabama Station might also accomplish the same result.

Wood seasoning offers an individual miscellaneous use of electricity which justify consideration in some localities. French experiments (110) have shown, for example, that the passage of an electrical current through a stack of green wood, placed in a large tank filled with a solution containing 10 per cent of borax, 5 per cent of resin, and a trace of sodium carbonate, drives the sap out of the timber and causes the deposition of borax and resin in its place, thus completely filling up all pores and interstices. Other experiments (111) showed that this process increased the resistance and strength of the wood and decreased its liability to decay. It thus seems possible that this process might be developed into a profitable use of electricity in some localities.

Undoubtedly other possibly profitable uses of electricity in miscellaneous farm practices might be brought to light by a careful study and analysis of the requirements and processes required in the detailed operations of different types of farming. The above few have been mentioned to illustrate the possibilities involved in such a development.

CONCLUSION.

A consideration of the results of this study seems to indicate that not enough of a fundamental nature is yet known regarding the exact requirements of the more important processes of specific types of farming with reference to the use of electricity as the required energy, to justify the immediate and arbitrary electrification of large rural areas without a previous and very definite knowledge as to how the electricity may be used profitably as a rather sizable and more or less constant load.

While a great amount of both fundamental research and investigation has been undertaken by different agencies, much disagreement on important specific points is evident. In other cases the work has never advanced much beyond the suggestive stage, although the progress findings have been quite promising. In still other instances such as tillage the fundamental principles of the practice itself have never been established, thus indicating the necessity first for fundamental research on the process and then for developmental research on the machinery required to perform the process before electricity can be applied effectively and economically as the source of required power.

In a very few cases the agricultural facts are apparently pretty well established and the remaining work amounts merely to the determination of the requirements for electrical energy and an exercise of applied agricultural engineering. These cases seem to be very much in the minority, however.

It thus seems evident that the rational application of electricity to agriculture will require, first, a large amount of fundamental agricultural and engineering research to provide the backbone of the movement, and, second, a certain but gradually increasing amount of investigational work to determine power requirements and exact electrical applications. Both are important, but the first provides the logical basis for the second.

Regardless of the lack of fundamental knowledge of the subject, this study indicates that the opportunities offered by electricity for the scientific and economic development of agriculture are so great as virtually to demand serious and intelligent consideration of general rural electrification. The humanitarian side of the question alone is so weighty as to forcibly demand consideration. The convenience, safety, ease of control and general flexibility of electrical power are such great arguments in its favor as to justify the most extreme efforts to extend its use generally to agriculture. To do this profitably it must be done intelligently. To do it intelligently all the facts regarding the exact requirements of agricultural processes and practices must be known not only to best use the electricity but to properly time the operations to provide a constant as well as a large electrical load. Since it is obvious that these facts are not very generally known with reference to the use of electricity as the source of energy, the only solution is to resort to systematic research and investigation following a rational and intelligently prepared program with a view to effecting a gradual and substantial development of processes and practices such that electricity may be profitably and permanently employed in their operation.

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